JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**
IOM 312.F-98-004
January 7, 1998

TO: Distribution

FROM: A. B. Chamberlin

SUBJECT: Small-Body Ephemeris NAVIO File Format - Version 2

Overview

The small-body ephemeris file (SBEF) format has been changed and requires the use of new generating software and new readers. This memo explains the reasons for changing the format, how to use the new format, and who is responsible for maintaining the relevant software.

Why Change the Format?

The previous SBEF format [1-4] was designed to provide ephemerides for a limited number of small-bodies whose states would be computed at a given time. Thus, for maximum efficiency, ephemeris data (i.e. Chebyshev coefficients) for all bodies were stored in a single NAVIO item. This design was adequate for files of small-body perturbers (e.g. Ceres, Pallas, and Vesta) and mission target bodies (e.g. Eros and Mathilde).

With the requirements for the DS-1 mission came the need to provide small-body ephemeris files containing more than 100 bodies. To accommodate this requirement with the old file format would have produced inefficient readers and restricted the maximum number of bodies allowed on a single file. The new file format allows for ephemeris data to be stored in a single NAVIO item for N bodies (called the "combined" form and functionally identical to the old format) or stored in N separate NAVIO items for each body (called the "separate" form). In most cases, files will be in one of these two forms. However, the format allows for hybrid files combining both forms in one file. This design should provide the flexibility needed to handle future requirements. The complete description of the new SBEF format is shown in attachment 1.

New Software Use, Description, and Maintenance

This section describes the general process of creating and using typical SBEFs. A program called SBGEN v2.0 is used to create N SBEFs for N bodies. These N SBEFs are combined in a single file using the program SBCOMB v1.0 which creates either a "combined" or "separate" form SBEF. This SBEF is then read by the appropriate reader. For example, in the ODP, a "combined" form SBEF is read by the reader SBERDR.

SBGEN v2.0 is significantly improved over SBGEN v1.0. The new version integrates the states

directly from precise orbital initial conditions (ORB file), saves a series of test states within the fit interval, fits Chebyshev coefficients to states within the interval, compares the fit with the integrated test states, and reports the maximum error in the fit for each state component. The user can specify the fit tolerance to ensure the SBEF is sufficiently accurate. SBGEN v2.0 further improves on the previous version by eliminating the need to produce an intermediate ASCII file of states and eliminating any "double" integration over the same time span (i.e. integrating backward from initial epoch to the start time and then forward over the same interval).

The Solar System Dynamics group will be responsible for creating SBEF NAVIO files for delivery and maintaining the programs used therein. The Navigation Software group will be responsible for maintaining the subroutines required for reading "combined" form files for use in the ODP. Projects requiring other reading capabilities will be responsible for creating and maintaining such software. These responsibilities reflect the author's understanding and may change in the future.

References

1. Chamberlin, A. B., "Revised Small Body Ephemeris NAVIO File Format", JPL IOM 312.1-96-015, 9 May 1996.
2. Standish, E. M., "Small Body Ephemeris File Programs", JPL IOM 314.10-010, 15 March 1996.
3. Standish, E. M., "Small Body Auxiliary Files", JPL IOM 314.10-007, 29 February 1996.
4. Ekelund, J. E., "Software to Generate and Read a NAVIO Ephemeris File Containing Multiple Asteroids and/or Comets", IOM 312.9-95-044, 24 January 1996.

Attachments

1. Small-Body Ephemeris File Format Description - Version 2.0

Distribution

C. H.	Acton	R. A.	Jacobson	L. R.	Stavert
S.	Bhaskaran	M. S.	Keesey	F. M.	Stienon
W. E.	Bollman	V. N.	Legerton	R. F.	Sunseri
P. J.	Breckheimer	J. P.	McDanell	S. P.	Synnott
D. V.	Byrnes	P. R.	Menon	W. L.	Taber
J. K.	Campbell	J. K.	Miller	T. C.	Wang
P. W.	Chodas	T. D.	Moyer	B. G.	Williams
J. E.	Ekelund	W. M.	Owen	R. N.	Wimberly
J.	Ellis	J. E.	Riedel	L. J.	Wood
J. D.	Giorgini	R. B.	Roncoli	D. K.	Yeomans
G. R.	Hintz	E. M.	Standish		

Small-Body Ephemeris File Format Description

Version 2.0 - January 1998

General Description

The Small-Body Ephemeris File is a NAVIO formatted file of comet and asteroid ephemeris data represented as Chebyshev coefficients. The file may contain Chebyshev coefficients for several comets and/or asteroids.

Volume

The maximum size of the file in blocks is a function of the length of time covered, the number of Chebyshev coefficients per body, the time span per set of coefficients per body, and the number of small-bodies represented: typically 3.4 kilobytes/year/body + 0.5 kilobytes/body of header data. As an example, a file spanning 6 years and containing 12 coefficients fit over 32 day intervals for two bodies requires about 41.8 kilobytes.

Organization

The file is in the NAVIO format and organized into one of three possible forms: "combined", "separate", or "hybrid" (contains both "combined" and "separate" forms). Most small-body ephemeris files will not be "hybrid". The "combined" form means that the Chebyshev coefficients for *all* bodies are combined in a single record such that for a given time, the state for all bodies can be determined with a single NAVIO file read. There is a limit on the number of bodies in the "combined" section of a file (typically 32). Note that the previous version of the small-body ephemeris file format was very similar to a "combined" form file. The "separate" form means the Chebyshev coefficients are stored in separate records for each body. There is no limit on the number of "separate" bodies in a file (except the maximum file size must be within specified NAVIO limits). The details of these forms are described below.

Storage Medium

The file is intended to be stored on disk.

Program Usage

The Small-Body Ephemeris File is generated by numerically integrating an initial Cartesian state (at some epoch) over time spans sufficient to cover the requested ephemeris time span (repeated for each body on the file). If the initial state epoch is within the requested ephemeris time span, maximum accuracy is maintained by first integrating from epoch backward to the start time and then from epoch forward to the end time. The computed Cartesian states are fit using *Chebyshev routines* and the resulting interpolated states are then compared with arbitrary test states previously stored during the

integration. The maximum errors for each state component are compared with user specified limits which cannot be exceeded, ensuring the resulting file is within tolerance. The program **SBGEN** generates single-body Small-Body Ephemeris Files. The program **SBCOMB** combines single-body and/or multi-body files into one new multi-body file.

Detailed NAVIO Format Description

Note: all items in all groups are direct access (i.e. Random=True).

ID Group

This group contains information which may be used to identify the file.

Item	Type	RECS	LEN	Description
FILE-NAME	C*25	1	1	The unique identifier name of the file format: "SMALL BODY EPHEMERIS FILE".
VERSION	I	1	1	An integer version number associated with a particular description of this file's format. Currently VERSION=2. The previous version, 1, did not have this item defined. Therefore, version 1 is assumed by the absence of this item.
FILE-ID	C*12	1	1	A unique identifier, selected by the file creator, representing the set of small-bodies and their individual orbit solutions. It is recommended that every identifier begin with "SB-". For example, a file containing recent solutions of Ceres, Pallas, and Vesta may use "SB-CPV005". This item is patterned after the planetary ephemeris NAVIO file item called FILE-NUMBER which is something like "DE-0403LE-0403".
PROGRAM-NAME	C*12	1	1	The name of the generating program: typically "SBGEN" or "SBCOMB".
EQUINOX	D	1	1	The Julian date of the equinox used in the generation of the file. This will be either 2433282.50D0 (for EME1950) or 2451545.0D0 (for J2000).
DE-USED	C*10	1	1	The character representation of the JPL Development Ephemeris (DE) number for the planetary ephemeris used to generate each small-body ephemeris. For example, "DE-0403", where "0403" specifies a particular ephemeris.
FINGERPRINTS	C*80	var	1	Each record contains the execution date/time, name/version, and link date/time of each program (typically SBGEN and SBCOMB) used to create the NAVIO file.

CONSTANTS Group

This group contains constants such as the number of bodies on the file, the Chebyshev fit interval, and the start/stop times for each body.

Item	Type	RECS	LEN	Description
NBODIES (*NB*)	I	1	1	An integer count of the number of small-bodies represented on the file.
NCOMBINED (*NC*)	I	1	1	Number of bodies in the *combined* section of the COEFFICIENTS group. *NC* may be any value between zero and *NB*, inclusive. The difference (*NB* - *NC*) indicates how many bodies are in the *separate* section of the COEFFICIENTS group.
BUFFER-SIZE	I	1	1	Length of each {COEFFICIENTS/DATA-RECORD} item (below). Could be zero if *NC*=0.
RECORD-SPAN	D	*	1	Record 1, if *NC*>0, contains the number of days spanned by each {COEFFICIENTS/DATA-RECORD} item (below). Also referred to as the "master interval" over which the Chebyshev polynomial fit was made. Subsequent records (if any) contain the number of days spanned in each corresponding {COEFFICIENTS/*short-name*} item.
START-JED	D	*	1	The start/first epoch (JED) of each small-body's ephemeris. Record 1, if *NC*>0, contains the start epoch of all *NC* bodies in the "combined" section (i.e. in the {COEFFICIENTS/DATA-RECORD} item). Subsequent records (if any) contain the start epoch of each body in the "separate" section (i.e. in the corresponding {COEFFICIENTS/*short-name*} item).
STOP-JED	D	*	1	The stop/last epoch (JED) of each small-body's ephemeris. (See {CONSTANTS/START-JED}.)
AU	D	1	1	The value of AU used in the planetary ephemeris file DE-USED.

* **RECS** is equal to (*NB* - *NC* + *k*), where *k*=1 if *NC* is greater than 0 and *k*=0 otherwise.

SMALL_BODY Group

This group contains information about each small-body on the file.

Item	Type	RECS	LEN	Description
IAU-NUMBER	I	*NB*	1	The official IAU number assigned to the small-body, e.g. 243 for asteroid 243 Ida, or 1 for comet 1P/Halley. Note that these numbers are unique only within bodies of the same type (asteroid or comet); for example, there is both an asteroid 1 (Ceres) and a comet 1 (Halley). Furthermore, if the IAU has not assigned a number to the object, this field will have a value of zero.

OBJ-NUMBER	I	*NB*	1	A unique integer number assigned to the small-body by JPL, e.g. 2000433 for asteroid 433 Eros. OBJ-NUMBER is set to 2000000 + IAU number for an asteroid with an IAU number, 1500000 + IAU number for a comet with an IAU number, 3000000 + an arbitrary unique number for an asteroid without an IAU number, or 1000000 + an arbitrary unique number for a comet without an IAU number.
OBJ-NAME	C*56	*NB*	1	Official IAU name for the small-body, if it has been assigned a name; otherwise the official IAU designation for the body. Official IAU names can be lengthy, can contain spaces, and usually contain both uppercase and lowercase letters; official designations often begin with a numeric string, which is the year of discovery, and usually contain spaces.
SHORT-NAME	C*12	*NB*	1	A short name for the body, no more than 12 characters in length, and unique at least within the file. This name must not contain embedded spaces or lowercase letters. Examples are "MATHILDE" and "EROS". SHORT-NAMEs are used as the names of the items (if any) in the *separate* section of the COEFFICIENTS group and in the SIGMAS group.
OBJ-TYPE	C*8	*NB*	1	A character string indicating the type of the object, either "ASTEROID" or "COMET". Asteroids and comets may be included on the same ephemeris file.
GM	D	*NB*	1	The double precision values of GM (km**3/s**2).
RADIUS	D	*NB*	1	The double precision values of radius (in km).
MAG-PARS	R	*NB*	5	Magnitude parameters: For asteroids, the parameters are H and G. For comets, the parameters are M1, M2, K1, K2, and phase-coefficient.
ALBEDO	R	*NB*	1	The object's geometric albedo.
B-V	R	*NB*	1	The object's color index: B-V.
SPEC-CLASS	C*6	*NB*	1	The object's Tholen spectral class. Blank if unknown.
ROT-PERIOD	R	*NB*	1	The object's rotation period in hours. Zero if unknown.
NON-GRAVS	D	*NB*	2	Non-gravitational parameters A1 and A2 (e-8 AU/d^2) in the transverse and radial directions (respectively). The radial direction is from the sun to the small-body and the transverse direction is normal to the radial direction, in the orbit plane, and in the general direction of the the object's velocity.
CENTER	I	*NB*	1	The body NAIF ID used as the center of integration.
SOLUTION-ID	C*20	*NB*	1	The character identifier of the orbit solution used to generate the ephemeris.
CREATE-TIME	C*25	*NB*	1	A character representation of the creation date/time of each body's ephemeris.
STEP-USED	D	*NB*	1	The step size, in days, used to generate the ephemeris for each small-body.

PRODUCER-ID	C*56	*NB*	1	The name of the analyst who generated the small-body ephemeris.
SBE-USED	C*20	*NB*	1	The character representation of the JPL small-body perturber ephemeris (SBE) number (as defined in FILE-ID) for the perturbing ephemeris used to generate the small-body ephemeris (blank if none used). For example, "SB-CPV001", where "CPV" indicates Ceres, Pallas, Vesta (all used), and "SB-CPV001/3" indicates the 3rd perturber (Vesta) was excluded.
COMMENTS	C*80	*NB*	1	This item may contain any character data that the producer provided when creating the ephemeris.
EPOCH-JED	D	*NB*	1	The epoch of the reference/initial state, expressed in Julian Ephemeris Date form.
EPOCH-STATE	D	*NB*	6	Inertial-frame Cartesian heliocentric position and velocity of the small-body at its epoch. The frame used is that of the planetary ephemeris identified in DE-USED. The units are AU and AU/d.
SIGMA-SCALE	D	*NB*	1	The scale factor applied to the formal covariance used to generate the ephemeris uncertainties (if any) which are stored in item {SIGMAS/*short-name*}. If SIGMA-SCALE is zero, no uncertainty data exist for that body.

POINTER Group

This group contains info necessary to locate Chebyshev coefficients for any given small-body. The first two items (COEFF-PTR and NCOEFF-SETS) are required only for the *combined* section (if any) of the COEFFICIENTS group.

Item	**Type**	**RECS**	**LEN**	**Description**
COEFF-PTR	I	1	*NC*	Location of the first coefficient for body *i* within a {COEFFICIENTS/DATA-RECORD} item. Defined only for the first *NC* small-bodies on the file.
NCOEFF-SETS	I	1	*NC*	The number of subintervals within the "master interval" {CONSTANTS/RECORD-SPAN} for the first *NC* small-bodies.
NCOEFFS	I	*NB*	1	The number of the Chebyshev coefficients per Cartesian coordinate for each small-body on the file.

COEFFICIENTS Group

This group contains records of double precision data consisting of Chebyshev coefficients for each small-body. This group is divided into two sections: the *combined* section and the *separate* section. Either or both sections may be present. The *combined* section contains *NC* bodies and corresponds to the {COEFFICIENTS/DATA-RECORD} item and the *separate* section contains *NB-NC* bodies and corresponds to the {COEFFICIENTS/*short-name*} item(s).

The data are such that a subroutine to read and interpolate this file for a given body *i* within a given time span may provide the position, velocity and acceleration of the requested body relative to the central body {SMALL_BODY/CENTER}(*i*). Interpolation of the coefficients using the reader SBPV provides positions, velocities and accelerations of the small-bodies in kilometers, kilometers/sec, and kilometers/sec**2.

Item	Type	RECS	LEN	Description
DATA-RECORD	D	*	*	The combined set of Chebyshev coefficients for the first *NC* small-bodies. The coefficients are separated into time spans specified by {CONSTANTS/RECORD-SPAN}(1) days from the start and stop dates (JED) specified in words 1 and 2 of the record (respectively). The remaining words of each record contain Chebyshev coefficients for each Cartesian component (*x*,*y*,*z*) for each small-body in the file. The number of (*x*,*y*,*z*) sets of coefficients for body *i* is specified by {POINTER/NCOEFF-SETS}(*i*).
short-name	D	*	*	The set of Chebyshev coefficients for the single small-body *i* (*i*>*NC*) with the specified *short-name*. These items are given only for the *separate* section small-bodies (i.e. bodies *NC*+1 through *NB*). The time span for the first of these items is defined in {CONSTANTS/RECORD-SPAN}(*j*) where *j*=1+(*i*-*NC*). Implicitly, {POINTER/NCOEFF-SETS}=1 and {POINTER/COEFF-PTR}=3 for these items.

* **RECS** is [{SMALL_BODY/STOP-JED}(*i*) - {SMALL_BODY/START-JED}(*i*)] / {CONSTANTS/RECORD-SPAN}(*j*) where *j*=1+(*i*-*NC*) for *i*>*NC*, and *j*=1 otherwise.

* **LEN** is equal to the sum of each body (*i*) of 2+3*{POINTER/NCOEFFS}(*i*)*{POINTER/NCOEFF-SETS}(*i*). This value is stored in item {CONSTANTS/BUFFER-SIZE}.

The format of each record in DATA-RECORD is the sequential ordering of the following parts:

- Start and stop JEDs of the master interval {CONSTANTS/RECORD-SPAN}(1).
- Coefficients for body 1.
- Coefficients for body 2.
- ...
- Coefficients for body N (N = *NB*).

where the "Coefficients for body N" are structured as follows:

```
-  Coefficients for the x-component of subinterval 1 for body N.
       "        "   "  y-component of subinterval 1 for body N.
       "        "   "  z-component of subinterval 1 for body N.
-  Coefficients for the x-component of subinterval 2 for body N.
       "        "   "  y-component of subinterval 2 for body N.
       "        "   "  z-component of subinterval 2 for body N.
                                .
                                .
                                .
```

```
-  Coefficients for the x-component of subinterval M for body N.
        "         "    "  y-component of subinterval M for body N.
        "         "    "  z-component of subinterval M for body N.
                                                  (M=NCOEFF-SETS(N)).
```

SIGMAS Group

This *optional* group contains the 1-sigma position uncertainty for selected small-bodies on the file, expressed in the RTN reference frame. Records are stored at the body's coefficients interval *N* (*). Uncertainty data are available for body *short-name* only if item *short-name* exists. If this group isn't present, then no uncertainty data exist for any body.

Item	Type	RECS	LEN	Description
short-name	D	*	7	Contains records of ephemeris uncertainties (1-sigma values, km) for the small-body identified by *short-name*. The first element is the time (JED) of the position uncertainty. The next 3 elements are the 1-sigma values in the RTN coordinate system, and the last 3 elements contain square-root covariances (R-T,R-N,T-N). Each record starts with a specified time JED with *N* days between records. The first record is at the ephemeris start time {SMALL_BODY/START-JED}, and the last record is at the end time {SMALL_BODY/STOP-JED}.

* *N* = {CONSTANTS/RECORD-SPAN(*j*)} / *NSS* where *NSS* = 1 for *i*>*NC*, and *NSS* = {POINTER/NCOEFF-SETS(*i*)} otherwise.

* **RECS** = [{SMALL_BODY/STOP-JED}(*i*) - {SMALL_BODY/START-JED}(*i*)] / *N*.

* *j* = 1+(*i*-*NC*) for *i*>*NC*, and *j* = 1 otherwise.

Last revision: 1998 January 07 (Alan B. Chamberlin)